POPULATION AND BIOLOGY OF THE COMMERCIAL SCALLOP (*PECTEN FUMATUS*) IN JERVIS BAY, NSW

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Following a peak in 1981/82, the commercial scallop fishery in Jervis Bay declined to the point where the dredge fishery finished in 1984 and the dive fishery in 1989–90. Despite past economic importance, little information was available on the biology of *Pecten fumatus* in Jervis Bay. Two small, low density, scallop beds in the south and north of the bay had different densities. Most scallops were found at depths of 15–20m. Density increased from 1990 to 1992. Recruitment events occurred in November 1989, November 1990 and in March 1991. Three groups that may be age classes 0+, 1+ and 2+ years were identified in each year. Lower reproductive activity occurred from December to March and 3 or 4 periods of higher activity occurred between April and December, suggesting multiple spawning behaviour. There was poor correlation between water temperature and gonad index, but significant correlation was found between increasing numbers of parasitised scallops and period of increasing water temperature. Main settlement occurred from November to January. It appears that there are factors which prevent successful settlement in locations other than the two main beds. There was a greater settlement at depths of 8–14m.

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In 1988 a study was initiated in Jervis Bay to provide baseline information on commercial molluscs for a management plan. Four species are of economic interest but this study deals only with the commercial scallop (*Pecten fumatus*), which has been the basis of an intermittent fishery since 1970.

Historical information (Hamer & Jacobs,1987; Young & Martin,1989) suggests that commercial scallop harvests in NSW were high in the early 1970's, but there is no indication of the total production in Jervis Bay. However, during the fiscal year 1981–1982 the fishery reported 2,822 tonnes (Stewart et al.,1991) for NSW with 1,329 tonnes comming from Jervis Bay. Anecdotal information suggests that up to 35 dredge boats and an unknown number of commercial scallop divers were operating in the bay during the 1981–1982 peak in the fishery. The dredge boats stopped operating in 1983–84 when the scallop fishery became uneconomic. The divers persisted until the end of 1990, although they have harvested <10 tonnes per annum in recent years. Recreational divers harvest scallops in Jervis Bay, but there are no catch estimates. Due to the low density of scallops, the NSW Department of Fisheries recommended a total closure of the fishery from November,1991 to June,1994 to allow stock recovery.

The aims of population level work were to provide information on distribution, abundance, size composition and settlement. The aim of work at the individual level was to increase the knowledge of the reproductive cycle.

MATERIALS AND METHODS

Population Surveys

The distribution and abundance of scallops (Fig.1) were estimated during grid and transect dive surveys during 1989–1991 (Fuentes et al., 1992). Random transect surveys in February 1990 and 1991 (Fuentes et al.,1992) examined populations in areas identified during grid surveys as having high concentrations of scallops. In April 1992, 35 transects were allocated to each area. In the transect surveys, scallops were classified according to size: small (flat shell <30mm), medium (30–60mm) and large (>60mm). The length categories were chosen on basis of the length-age relationships (Hamer, 1987). Transects containing scallops were grouped into: high density transects (>0.1 scal $/m^2$) and low density transects (<0.1 scal/m^2).

Population size structure was based on length-

FIG.1. Location of Jervis Bay.

frequency surveys in the Murrays Beach bed (Fuentes et al.,1992). Only data from surveys between September, 1989 and August, 1991 are included herein. All samples were taken from the Murrays Beach bed by 2–3 divers who collected all scallops that they saw during 40–50min dives in 17–20m. The collections were assumed to estimate the actual length-frequency distribution of scallops in the bed.

Reproductive Biology

Regular collections of 50 scallops of commercial size (>65mm) were taken by SCUBA divers from the Murrays Beach bed. Monthly or fortnightly samples were taken according to the state of the gonads. Based on the assumption that the gonad weight of mature individuals changes in relation to total body weight during the breeding season, a gonosomatic index (GSI) was used as indicator of reproductive condition (Grant & Tyler,1983; Barber & Blake,1991). A GSI was calculated for each nonparasitised scallop: GSI = (GW/BW – GW) * 100, where GW is the gonad weight and BW is the body weight in grams. Mean GSI values and frequencies of parasitised scallops were correlated to weekly bottom temperatures from near the collecting site.

Macroscopic and microscopic examinations of gonads were conducted to investigate scallop reproductive behaviour and to implement an easy and rapid technique to assess the reproductive condition of scallops. In the macroscopic study, dissected gonads were classified into 7 stages: Immature, Developing 1, Developing 2, Ripe, Spawning 1, Spawning 2 and Parasitised. In the microscopic study, the female sections of the gonads were classified into 9 stages: Immature, Early development, Ripe, Partial spawning, Extensive spawning, Resorption, Resting and Parasitised.

Settlement

A longline system with collector bags acting as artificial substrata was used to study the spatial and temporal characteristics of scallop settlement. From August 1989 to February 1990 settlement was studied near the Murrays Beach and Honeymoon Bay scallop beds. From August 1990 to February 1991, Plantation Point, Huskisson and Green Point were added for settlement studies. For detailed descriptions of the sampling design and location of collectors see Fuentes et al. (1992).

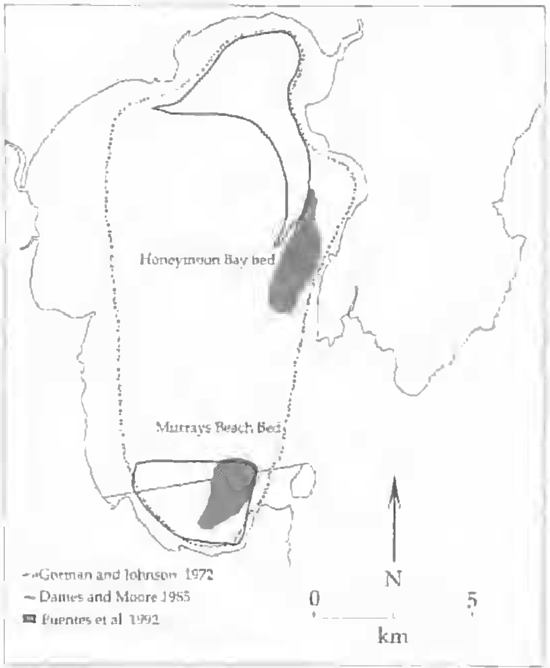

FIG.2. Distribution changes of the commercial scallop, *P. fumatus*, in Jervis Bay. The straight line is the boundary between State and Commonwealth waters.

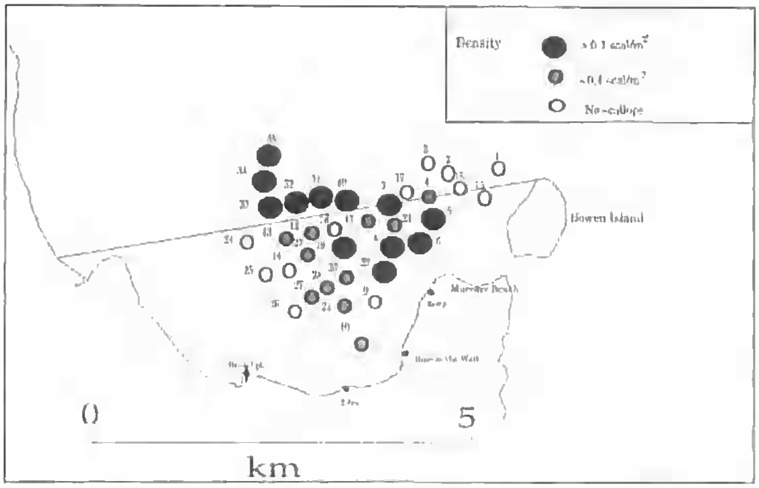

FIG.3. Location of transects at Murrays Beach Bed in April 1992. Figures on the circles are transect numbers.

RESULTS AND DISCUSSION

Population Surveys

DISTRIBUTION: The first assessments of commercial scallop distribution including abundance were obtained from the dredge surveys conducted by FRV Kapala during the 1970 and 1971 peak in the scallop fishery (Gorman & Johnson,1972). No further scallop investigations were conducted in Jervis Bay until the fishery boomed again in the early 1980's. At this time a dive survey (Butcher et al.,1981) and a number of other studies (Jacobs,1983; Hamer,1987; Hamer & Jacobs,1987; Williams & Diver,1988; Fuentes et al.,1992) indicated that *P. fumatus* occurred throughout the bay (Fuentes et al.,1990).

Commercial scallops were primarily confined to Murrays Beach and Honeymoon Bay (Fig.2), with only few individuals observed elsewhere. More scallops were found between 15–20m than between 5–15m. What constrained the commercial scallop to this distribution is unknown, but natural environmental changes, fishing methods, overfishing or a combination of factors should be examined.

Dredging was the most common method of harvesting scallops in Jervis Bay during the years of intensive fishing. Although some studies have alleged that dredging has no adverse effect on scallops (Butcher et al.,1981), other authors have suggested that dredges both cause considerable damage to scallops that are left in the dredge track (Caddy,1973, McLoughlin et al.,1991) or cause detrimental changes to the bottom (McLoughlin et al.,1991, Riemann and Hoffmann,1991) which prevent or inhibit scallop settlement. However, it

TABLE 1. Sampling effort and abundance of scallops in the two main scallop beds in Jervis Bay during transect dives in February 1990, February 1991 and April 1992. [a] include only transects with scallops.

	Murrays Beach			Honeymoon Bay			TOTAL		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
No. of transects	35	35	35	34	35	35	69	70	70
Area covered (m^2)	2100	2100	2100	2040	2100	2100	4140	4200	4200
Mean dive time (min)	9.8	9.5	10.3	10.1	7.9	7.7			
Transects with scallops	19	20	23	14	12	20	33	32	44
Transects without scallops	16	15	12	20	23	15	36	38	26
Total scallops	149	150	1367	42	33	156	191	183	1523
Small scallops (<30mm)	21	76	9	3	5	8	24	81	17
Medium (31–60mm)	46	33	1109	11	13	88	57	46	1197
Large scallops (>60mm)	82	41	249	28	15	60	110	56	309
Mean scallops/transect[a]	7.8	7.5	59.43	3.0	2.7	7.42	5.8	5.7	34.66
Mean scallops/all transects	4.3	4.3	39.0	1.2	0.9	4.5	2.4	2.6	21.7
Density (per m^2)[a]	0.129	0.125	0.991	0.051	0.046	0.124	0.096	0.095	0.577
Total density (per m^2)	0.071	0.071	0.650	0.021	0.016	0.087	0.046	0.043	0.073

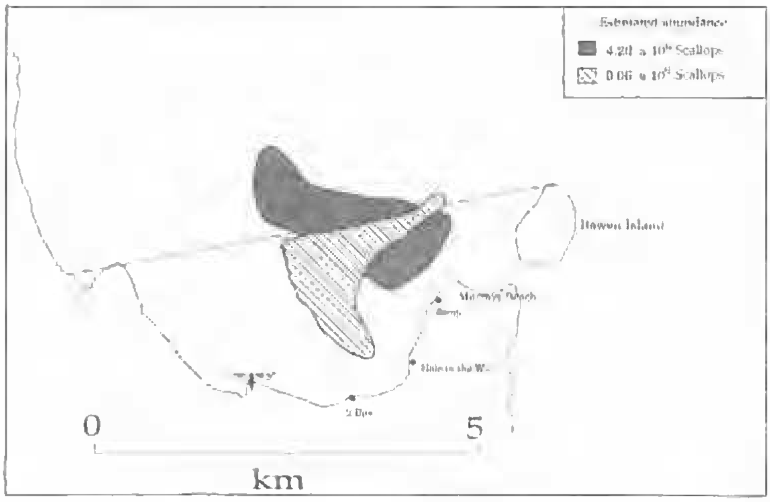

FIG.4. Survey areas showing the differential abundance of commercial scallops in the Murrays Beach Bed during the transect survey in April 1992.

is still not known if fishing technique was the only factor responsible for a decrease in these fisheries.

ABUNDANCE: Dredge surveys and dive surveys provide similar estimates of scallop distributions (McShane,1982; McShane & O'Connor,1982); however, dive surveys yield more precise estimates of abundance although the estimates typically are lower. There were no dredge vessels operating in Jervis Bay during the time of this study, therefore, only estimates from dive surveys were available.

The Murrays Beach bed typically contained a relatively low density of scallops, and the Honeymoon Bay bed was even more sparcely populated. However, a comparison of transect surveys in 1992 with previous surveys in 1990 and 1991 (Table 1) indicated differences in the abundance of the three size classes and an increase in the total number of scallops. At both locations, the number of medium size scallops were more abundant in 1992 than in previous years, which suggest improved recruitment to the fishery.

In the 1992 transect survey at the Murrays Beach bed, scallops were found in only 23 transects. The average number of scallops in all transects was 0.991 scal/m^2 (SE = ±0.264). The location and scallop density for each transect (Fig. 3) identified the E–W boundaries of the bed, but it did not identify the northern limit of the bed which extends towards the middle of the bay. Within the bed, areas of high (>0.1scal/ m^2) and low (<0.1scal/m^2) density were identified (Fig.4). The high density area (2.3km^2) contained 4.20x10^6 scallops while the low density area (1.6km^2) contained c.0.06x10^6 scallops (Table 2). The bed occupied 3.7km^2, and interpolation among the most external transects containing scallops indicated that the bed contained 3.66x10^6 scallops.

This exercise was repeated at Honeymoon Bay where 20 transects contained scallops (Fig.5). The average number of scallops per m^2 in all transects with scallops was 0.130 (SE = ±0.039). Plotting the location and density for each transect defined the boundaries of this bed (Fig.6). The high density area (>0.1scal/m^2) was almost completely surrounded by a low density area (<0.1scal/m^2). The high density area (2.3km^2) contained 0.61 x 10^6 scallops (Table 2). The total area of 6.0km^2 contained approximately 0.78 x 10^6 scallops.

TABLE 2. Mean of scallop density and estimation of abundance at 2 locations in Jervis Bay during April 1992. Abundance estimates were calculated using only those transects containing scallops.

	Av. Scal/m^2	95% confidence limit		St. error	No. of Transects	Est. area (km^2)	Abundance (x10^6)
		Upper	Lower				
Murrays Beach							
Density/transect	0.991	1.538	0.443	0.264	23	3.7	3.66
high density	1.865	2.633	1.097	0.349	12	2.3	4.20
low density	0.036	0.049	0.023	0.006	11	1.6	0.06
Honeymoon Bay							
Density/transect	0.130	0.223	0.037	0.039	20	6.0	0.78
high density	0.273	0.449	0.097	0.034	8	2.3	0.61
low density	0.035	0.047	0.022	0.006	12	6.0	0.78

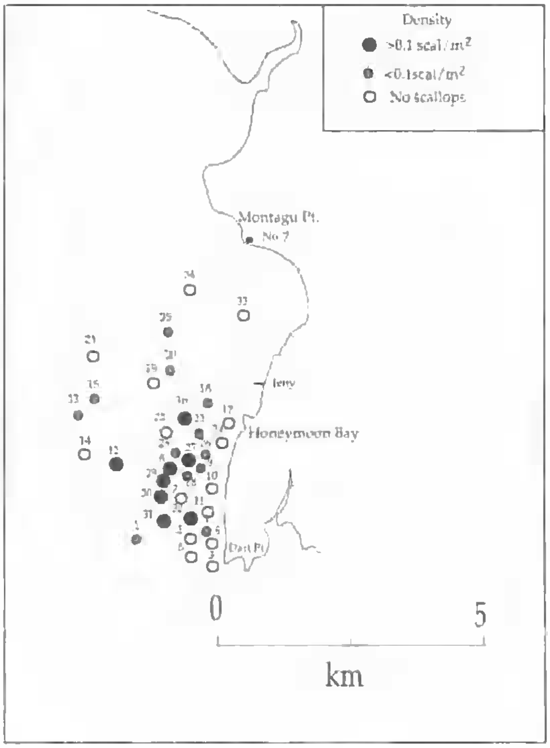

FIG.5. Location of all transects at Honeymoon Bay. Figures on the circles are the transect numbers in April 1992.

SIZE STRUCTURE:The population size composition and progression of the modal size classes (Fig.7) illustrate variations in size composition through time. At least two size classes were evident in most samples. The number of scallops increased in the last six samples and the highest numbers of small scallops were also taken near the end of the investigation.

The first recruitment observed during this study occurred in November 1989 when two cohorts were observed; one with a mode in the 28mm class-size and a second in the 63mm class-size. On the basis of Hamer's (1987) ageing criteria, the first cohort could represent a 0+ age group and the second a mixture of 1+ and 2+ age groups. The two cohort structure seen in November 1989 and January 1990 persist until May 1990. From July 1990 to September 1990, the population size distribution was unimodal with no cohort components.

A second recruitment pulse appeared in November 1990. A few individuals of 28mm (0+ year of age class) suggest a small recruitment, or less than that of the corresponding month in the previous year (November 1989). The sample from January 1991 showed the 0+ age group seen in November 1990 at 43mm.

The sample from March 1991 showed 2 size groups similar to those observed in November, 1989. This suggests that the main recruitment in the second year of this study occurred 4 months later than in the previous season. From March to May 1991, the two cohorts were evident, but they merged again by July 1991.

Small scallops are hard to see, and only one sample (March, 1991) had any individuals <10mm in shell length. Scallops <20mm shell length were also found in few samples (November, 1989, January, 1990, March and May, 1991). The collection of small individuals coincided with estimated recruitment times. Small scallops were collected from around the bases of seaweed, arborescent polychaetes and sponges. Medium and large individuals were more conspicuous as they were only partly buried in the sandy sediment. They shared the substratum with polychaete hummocks but were not always near the base of emergent benthic organisms.

Differences in recruitment from one year to

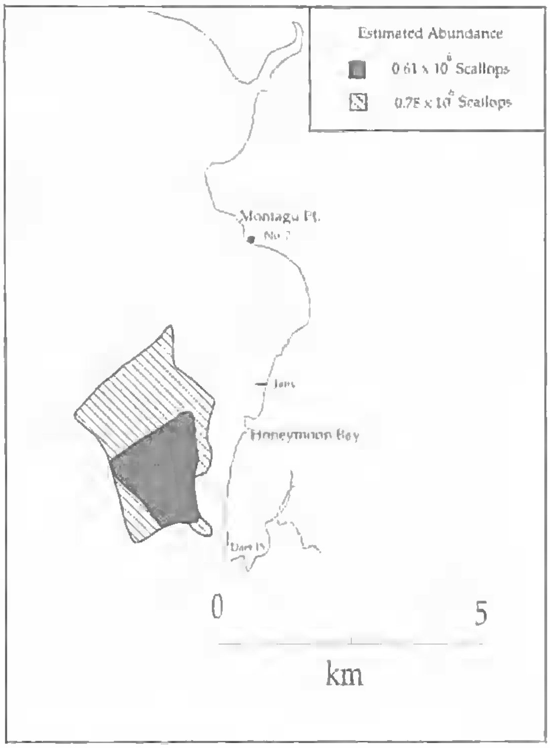

FIG.6. Areas of differential abundance of the commercial scallops at Honeymoon Bay in April 1992.

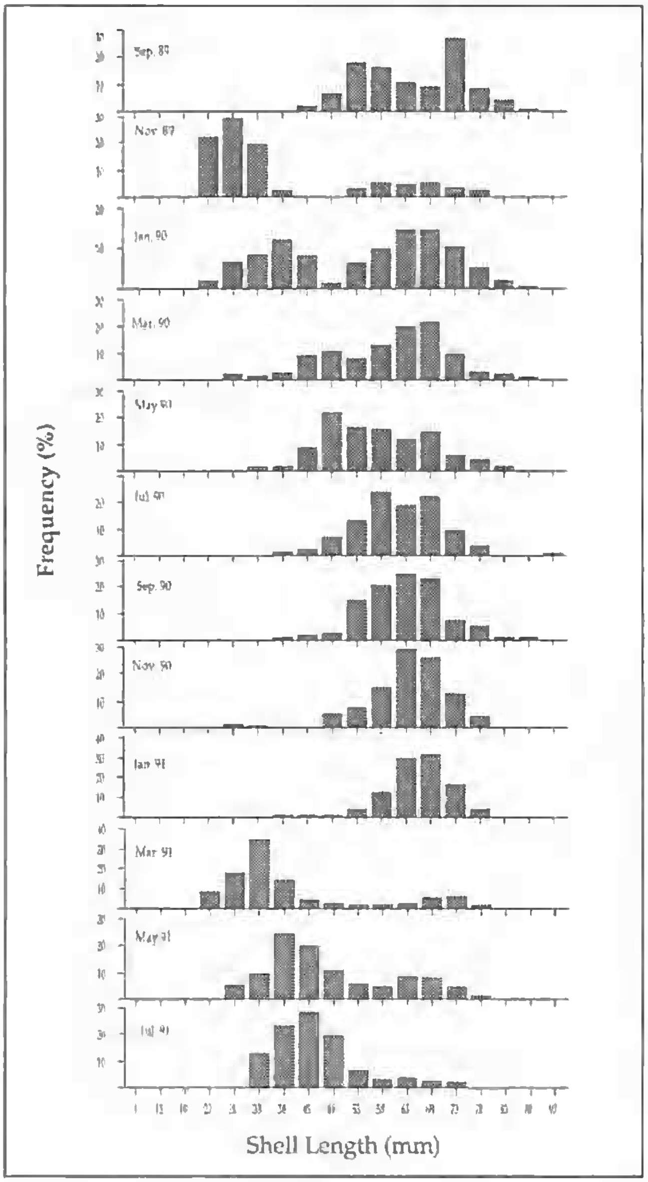

FIG.7. Length-frequency histograms for Jervis Bay commercial scallops from September 1989 to July 1991. Class-size interval = 5mm.

another like those observed for the commercial scallop in Jervis Bay (Table 3), are typical of scallop species and appear to be influenced by changes in oceanographic conditions such as temperature and nutrient availability. Settlement and post settlement conditions in 1989 may not have been the same as in 1990 or 1991.

Biological Studies

Reproductive Cycle:

Gonosomatic index (GSI): Two periods of low GSI were December 1989 to March 1990 and November 1990 to March 1991 (Fig.8). Four peaks occurred in the 1989/90 cycle (August to September, mid-November, mid-April to mid-May and after mid-July), and four during the 1990/91 cycle (mid-August, late October, late April and mid-May). In both years, each peak was followed by a decrease in GSI, which may correspond to a partial spawning event. Jacobs (1983) described a similar situation, with at least 3 spawning peaks in Jervis Bay: late winter to early spring, early summer and late autumn. The reproductive cycle of *P. fumatus* in Port Phillip Bay (Sause et al.,1987a,b) showed a similar pattern with some gamete release taking place in winter and a major release in late spring. Regional differences in spawning behaviour may exist among *P. fumatus* populations in South Australia, eastern Victoria, southern New South Wales and Tasmania.

Parasitised gonads were present in every sample (Fig. 9), although the frequency increased from January to June 1990 and from November 1990 to March 1991. There was no obvious temporal pattern in the occurrence of parasitised gonads, but the mean frequency of occurrence from August 1990 to July 1990 was higher than the similar period in the year 1989–1990. The degree of infestation may be indicated by the orange and red in the parasitised gonads. An orange gonad could be the early stage of infestation in which animals are still reproductive. A red gonad could be a final stage of infestation resulting in total loss of reproductive capacity.

Many exogenous factors influence reproduction in scallops, but temperature and food are most important (Macdonald & Thompson,1986; Barber & Blake,1991). The annual average bottom temperature (18.17°C from August 1989 to July 1990 and 19.02°C from August 1990 to July 1991) were significantly different when compared in an ANOVA (df=1, MSE=18.60, F=16.18, P>0.0001).

Temperature data were correlated with GSI and

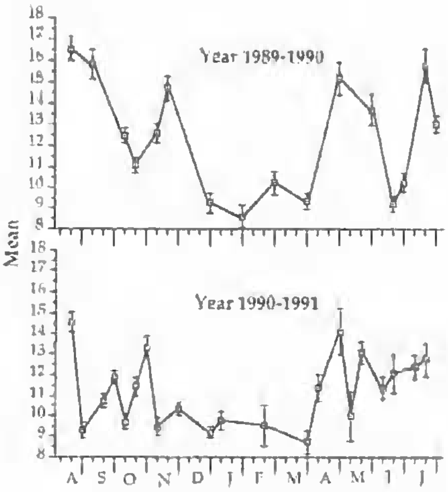

FIG.8. Commercial scallops gonadosomatic index (GSI) from August to July in two consecutive years in Jervis Bay.

frequency of parasitised scallops. Temperature has been positively correlated with GSI in other species (Paulet & Boucher,1991), but in this study such a correlation was not clear. During the first year, the correlation coefficients between bottom temperature and GSI have negative values and are not significantly different over lags of up to 3 previous weeks. In the second year, such correlations are not significant. The correlation coefficients between bottom temperature and the frequency of parasitised scallops are not significant in the first year, but in the second year, the correlation coefficients are significant over lags of up to 3 weeks.

Bottom temperature did not seem to have a direct influence on GSI, however, the positive correlation between temperature and frequency of parasitised scallops may be a factor that reduces the reproductive capacity of the scallop

TABLE 3. Comparison between settlement on collectors and recruitment of the commercial scallop in Jervis Bay.

	1989-1990		Recruitment 1991	1990-1991		Recruitment 1992
	Mean	SE		Mean	SE	
Oct-Dec	12.72	0.84		79.89	8.32	
Nov-Jan	7.22	0.93		22.33	20.6	
Dec-Feb	0.06	0.006		4.94	0.90	
Abundance (Scal/m^2)			0.13			0.99

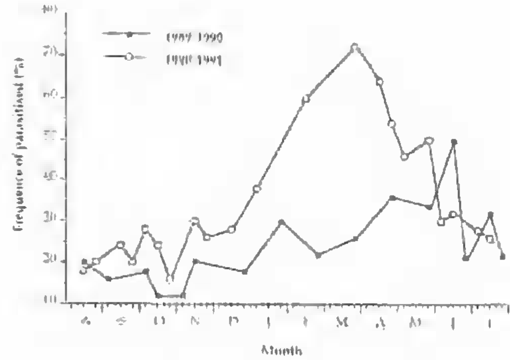

FIG.9. Percent frequency of parasitized scallops in Jervis Bay during the sampling period from August 1989 to July 1991.

population by increasing the number of infertile individuals. A year of low temperatures followed by one or more of high temperatures (such as the period August 1989 to July 1991) could reduce recruitment in subsequent years.

Macroscopic staging: The majority of gonads in all samples were in the Developing 2 or Spawning 1 stages (Fig.10). The Developing 2 stage made up >40% of the samples in October and May of both years and September and December of 1990. The second most common stage, Spawning 1, peaked between February and March, June, August and November of 1990 and in March 1991. The number of ripe gonads peaked in November 1989 and April 1991 but smaller peaks occurred throughout the year. Spawning 2 gonads peaked in late August of 1990, showed smaller peaks in the previous January and June, and showed no strong peaks in the second year of sampling. In the first year, there was a greater percentage of gonads in spawning condition (Spawning 1 and Spawning 2 stages) than in the second year. In the second year, there were more developing gonads (Developing 1 and Developing 2 stages) and ripe gonads.

Observer experience is needed to make correct classifications and determine macroscopic stages. For example, differences in gonad thickness between Developing 1 and Developing 2 stages, and differences in the turgor of Ripe and Spawning 1 gonads are determined subjectively. Presence of the alimentary loop and its visual characteristics are also subjectively determined. The colour and outline of the loop depends on the type and amount of food eaten and the position of the loop within the gonad. Sometimes the loop

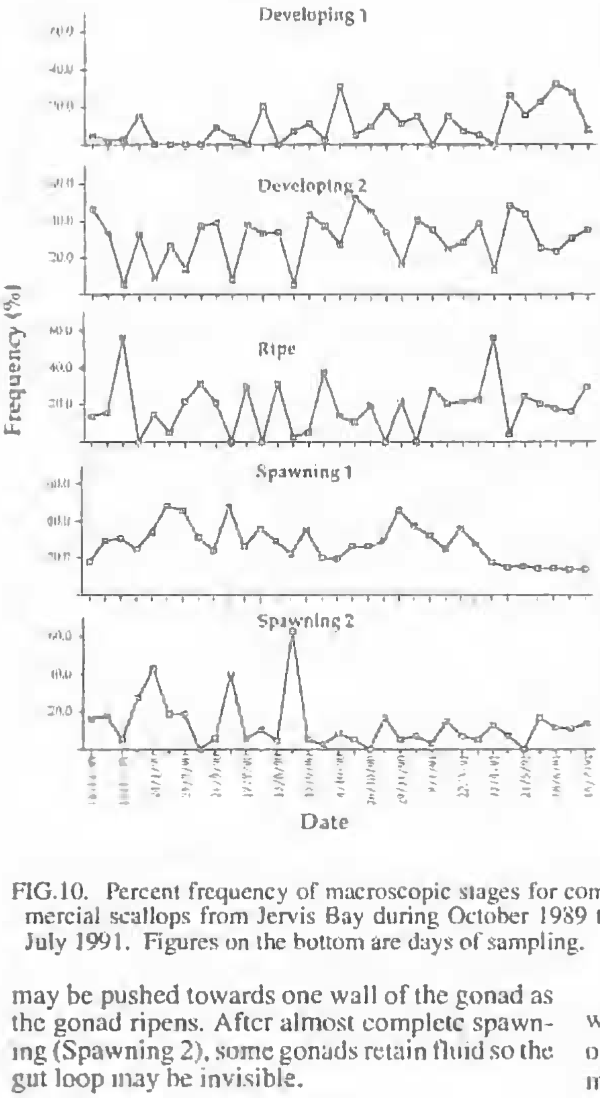

FIG.10. Percent frequency of macroscopic stages for commercial scallops from Jervis Bay during October 1989 to July 1991. Figures on the bottom are days of sampling.

may be pushed towards one wall of the gonad as the gonad ripens. After almost complete spawning (Spawning 2), some gonads retain fluid so the gut loop may be invisible.

Microscopic staging: No specimens were in the Immature or Early Development stages as the samples contained only adults. All other microscopic stages were present most of the year (Fig.11). Developing, ripe and resorbing scallops occurred in 11 of 12 months with peaks in May, April and July, and April and May respectively. The Partial Spawning stage was present in all 12 months with a peak between February and March and the Extended Spawning stage was found in 9 of the 12 months. Resting gonads were present during summer (December, January, February) and winter (June, July, August). Resting gonads were most numerous in December and June.

The Partial Spawning stage occurred every month, the Resorption stage occurred in all months except one, and the Extended Spawning stage was not numerous. Therefore, the commercial scallop in Jervis Bay spawns a number of times during the breeding season. It seems unlikely that complete spawning with an entire release of gametes occurred in Jervis Bay.

Histologic examination of gonads is important to confirm spawning, as a drop in the gonadosomatic index (GSI) may indicate resorption. If resorption is high, fecundity estimates are not related to the numbers of viable eggs released (Tremblay,1988). The area of the gonad is also important in analysis because a previous test (Fuentes et al.,1992) showed that the fore region of the female part had significantly more oocytes per follicle than either the mid or tip regions. Furthermore, histological sections often showed an 'edge effect', i.e., the follicles had collapsed at the edges of the section and the oocytes were dislodged from the follicle walls. Consequently, gonads were only compared by taking sections from the same region of the gonads and making classification on the centres of the sections.

The finding that the Jervis Bay commercial scallops have extended dribble spawning is not unusual. In other species of scallops, mature gonads are present all year (Paulet et al.,1988) and partial spawning or more extensive spawning can occur in any month of the year (Coe,1945). Paulet et al. (1988) suggested that dribble spawning could be an adaptation to an unpredictable environment. The hypothesis is that at least some larvae will find favourable conditions and the chances of either very weak or very strong recruitment are minimised (Paulet et al.,1988).

Comparison of macro- and microscopic staging schemes: Classifications derived from macroscopic and microscopic staging were compared to determine whether a simpler technique would allow an accurate prediction of scallop reproductive behaviour. When the macroscopic and microscopic techniques were compared, the macroscopic stages Developing 1, Developing 2, Ripe, Spawning 1 and Spawning 2 were assumed to correspond with microscopic stages Early Development, Developing, Ripe, Partial Spawning and Extensive Spawning, respectively. The comparison gave a poor result, for example macroscopic staging consistently overestimated the condition of developing scallops (Fig.12). The accuracy of the macroscopic technique was

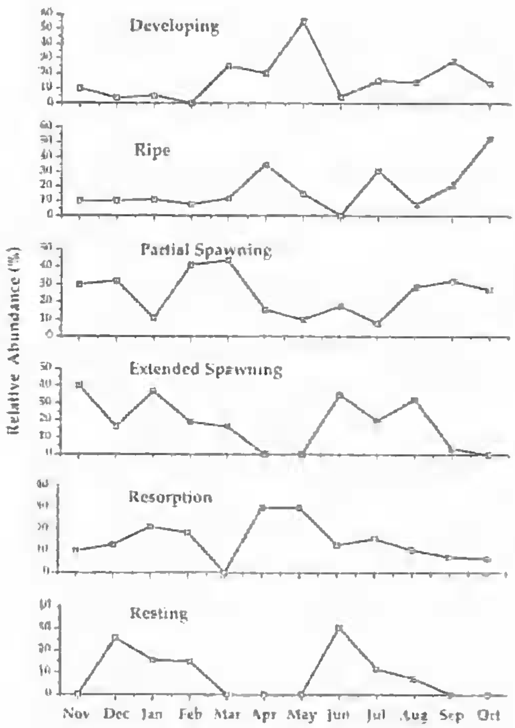

FIG.11. Relative abundance (%) of microscopic stages for commercial scallops from Jervis Bay. No specimens were in Immature or Early Development stages.

correct only c.50% of the time when classifying Ripe and Spawning scallops, with no consistency between the degree of over- or underestimation of gonad stage.

The lack of correspondence can only be partly explained. For example: some scallops gave the macroscopic appearance of being in Spawning 1 stage, but key histological features meant they were placed in the microscopic Resorption stage. It was not possible to macroscopically classify scallops as being in either the Resorption or Resting stage. For similar reasons, scallops appearing to be in the macroscopic Spawning 2 stage could have been in the Resorption or Resting stages. Another problem may have occurred when the loop of the alimentary canal was visible and the gonad was therefore classified in the Developing 2 stage, but the gonad would be classified as Ripe when viewed microscopically. When a gonad displayed orange spots it was allocated to Spawning 1 stage. However, if the section did not encompass the spotted area, the gonad would be classified as Ripe when viewed under the microscope. The first three of the scenarios above lead to an underestimation of gonad stage; the fourth leads to an overestimation.

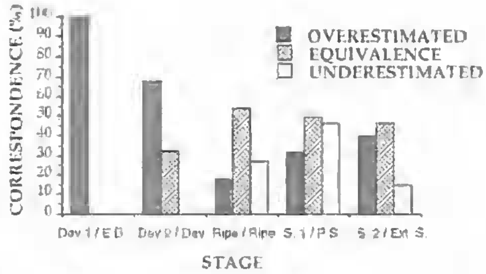

FIG.12. Correspondence between macro- and microscopic stages. DEV. 1=Developing 1; E.D.=Early Development; DEV.2=Developing 2; DEV.=Developing; S.1=Spawning 1; P.S.=Spawning 1; S.2=Spawning 2; EXT.S.=Extended Spawning.

Macroscopic and microscopic staging schemes have their own sets of advantages and disadvantages. Macroscopic staging is imperative where the animals cannot be sacrificed, and its relatively few stages are suitable for a rough classification of gonads while in the field or under hatchery conditions. However, the macroscopic scheme depends very much on the observer's ability to make correct classifications, e.g., scallops classified in Spawning 1 or Spawning 2 stages might really be in Resorption or Resting stages. The primary advantage of the microscopic scheme is that it provides a more accurate understanding of an individual animal's condition, but a lengthy period of time is required to prepare and process histological material. As Jervis Bay scallops do not appear to have a well defined reproductive cycle and they appear to dribble spawn, provision might need to be made for microscopic staging to follow their reproductive development during recovery of the population.

Settlement

Two studies were aimed at the spatial and temporal characteristics of scallop settlement in Jervis Bay. The first study, carried out on the two scallop beds assessed the magnitude, depth stratification and seasonality of settlement. The second study of 5 locations, initiated in September 1990 and finished in February 1991, ad-

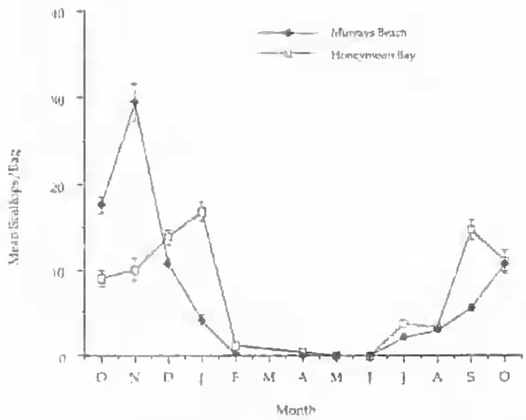

FIG.13. Mean and standard error of the number of commercial scallop spat settled by month at two locations in Jervis Bay (Oct 1989 – Oct 1990.

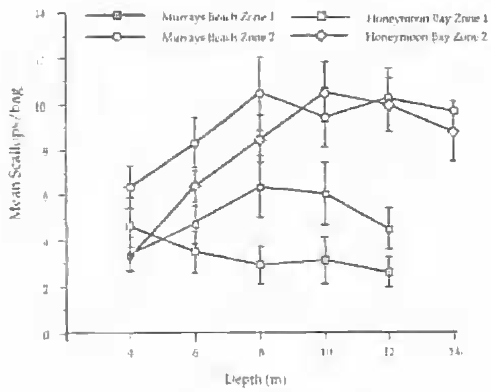

FIG.14. Mean and standard error of the number of scallop spat settled by depth stata, zone and site.

dressed the question of larval dispersion within the bay and allowed comparison of settlement between years.

In the first study, settlement data was analysed by time, location, zone and site according to the design described in Fuentes et al. (1992). Significant temporal variability was found in the mean number of spat that settled on the experimental longlines (Table 4). Maximum settlement was recorded from November to January (Fig.13). At both locations, settlement was minimal from February to June, but increased after July. Different temporal pattern in settlement were observed at Murrays Beach and Honeymoon Bay. It appeared that the duration of settlement was similar at both locations, but peak settlement seemed to occur two months earlier at Murrays Beach. The time of maximum larval abundance varies within *P. fumatus* (Young & Martin,1989). In Tasmanian waters between King Island and Banks Strait, similar temporal differences in settlement were found from one location to another, within the same location (Young et al.,1988), and from one year to the next (Hortle & Cropp,1987). Settlement begins in September (Young & Martin,1989) and continues to December, but at decreasing intensities, in southern Tasmania (Hortle & Cropp,1987). In eastern Bass Strait, settlement occurs November–December (Hortle,1983; Young et al.,1988).

Differences in settlement at the first two spatial scales (location and zone) were not significant, but the differences among sites (within zone and location), were significant, suggesting small scale patchiness in settlement of *P. fumatus* in Jervis Bay. Spatial variability in settlement of *P. fumatus* has been documented in Port Phillip Bay; differences were observed in the number of settling spat at sites only 30km apart (Gwyther et al.,1985; Sause et al.,1987b; Coleman,1988).

TABLE 4. Summary of analysis of variance (ANOVA) of scallop spat settlement at 2 locations, 2 zones and 3 sites over time at Jervis Bay. *0.01-p>0.001; **0.001=p>0.0001; ***p=0.0001; ns=no significance.

Source of variation	df	SS	F value	Sgnif.
Location	1	11.714	5.32	ns
Zone	1	12.301	12.30	ns
Location*Zone	1	4.850	2.20	ns
Site (Location*Zone	6	13.212	11.39	***
Time	8	979.800	107.83	***
Location*Time	8	133.110	14.65	***
Zone*Time	8	17.640	1.94	ns
Time*Site (Loc.*Zone	34	38.619	5.88	***
Location*Zone*Time	8	12.257	1.35	ns
Depth	5	7.704	5.16	***
Location*Depth	5	6.875	4.61	**
Zone*Depth	4	4.323	3.62	*
Time*Depth	40	25.612	2.15	**
Time*Depth*Site (Location*Zone)	286	85.380	1.54	***
Residual	812	156.964		

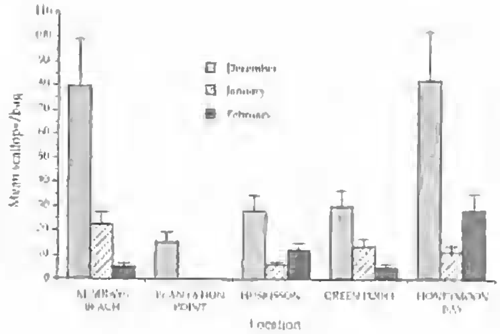

FIG.15. Mean and standard error of the number of scallop spat settled from December 1990 to February 1991 by location and time.

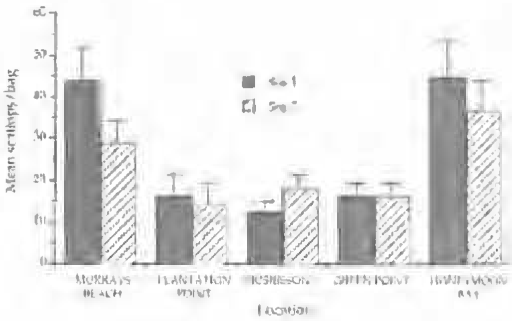

FIG.16. Mean and standard error of the number of scallop spat settled from December 1990 to February 1991 by location and site.

Similar variability occurs in Bass Strait in areas separated by larges distances (Young et al.,1992).

Mean numbers of spat that settled at different depth strata were significantly different. The highest settlement in Zone 1 (14m) was in the 8–12m Depth strata and in Zone 2 (18m) settlement was greatest at 8–14m (Fig.14). The lowest settlement was at the 4m depth stratum. Hortle & Cropp (1987) found that fewer spat settled near the surface and near the seabed (10–20m in a depth of 31m) in Mercury Passage on the east coast of Tasmania. Young et al. (1988,1992) reported that larvae tended to settle on collectors placed near the bottom rather than on those higher in the water column off northern Tasmania. A combination of water temperature (thermal stratification), with factors such as larval behaviour, could also influence settlement in Jervis Bay. Jervis Bay has a strong thermal stratification most of the year (Holloway et al.,1989,1990) and *P. fumatus* settlement, like that of other species (Milcikovsky,1973; Mann & Wolf,1983; Tremblay & Sinclair,1988), may be influenced by such stratification.

In the second study (September,1990 to February, 1991) settlement was observed in each of the five locations where longlines were placed (Fig.15). Significant spatial and temporal variability was found in the mean number of spat that settled on collector bags with variation occurring among the five locations, among the three times and between the two sites within each location. Comparisons of settlement at different depths show similarities to results of the first study: settlement was lower on collector bags placed near the surface than on those placed near the bottom. Comparisons indicated higher settlement at Murrays Beach and Honeymoon Bay (outer Bay) than at the other three locations (inner Bay). The temporal variations in this second study were similar to those in the first i.e. highest in December (Fig.16). However, in this year there were no differences in the timing of settlement between Murrays Beach and Honeymoon Bay.

It has been postulated that the larvae of *P. fumatus* may not disperse widely from the adult population and that the number of larvae reaching the pediveliger stage may be related to the size of the nearby adult populations (Mason,1983; Young et al.,1988). In Jervis Bay, there were differences between years in the mean number of spat that settled on collectors. More spat were observed in December 1990 than in December 1989 at both locations. The average number that settled per collector was higher at Murrays Beach probably because the abundance in the nearby population is higher than in Honeymoon Bay. Whether successful settlement in Jervis Bay is related to the proximity or size of the adult population is still to be demonstrated.

The low densities of the adult populations at Murrays Beach and Honeymoon Bay could be the reason for the low settlement during the study period. The settlement figures (average of 35 scallops/collector bag in November 1989 at Murrays Beach and 15 scallops/collector bag in January 1990 at Honeymoon Bay) are less than the average of 89 scallops/collector bag reported in 1982 off Huskisson (Jacobs,1983). Furthermore, figures for Jervis Bay are much lower than figures reported for eastern Tasmania (516 scallops/collector bag in 1982/83, 425 scallops/collector bag in 1984/85 and 325 scallops/collector bag in 1985/86, Hortle & Cropp,1987) and for Port Phillip Bay (Sause et al.,1987b).

From these two studies, it is concluded that scallop larvae were distributed around the bay and that there were limitations on settlement at areas other than the two main beds. One implication of this conclussion is that changes which inhibit settlement may have occurred in the habitat at some sites. This might be the reason why commercial scallops disappeared from areas they were abundant in the previous decade. A second implication derived from this study is that the presence of larvae in the water column, the timing of spat settlement and the variation in settlement with depth are relevant factors in the design of systems for the collection of wild spat.

The magnitude, stratification and timing of larval settlement and dispersion are important management issues for commercial scallop fisheries. Attempts have been made to relate *P. fumatus* settlement in one year to recruitment in subsequent years (Sause et al., 1987b; Gwyther & Burgess,1987; Coleman, 1988; Coleman & Gwyther,1988). Coleman (1988) found that successful settlement may not necessarily mean good subsequent recruitment. However, in this study differences in settlement were evident and they coincide with a greater adult densities recruitment observed in the Murrays Beach and Honeymoon Bay beds in the transect surveys in 1992.

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